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A POSITIVE-REPLICA TECHNIQUE FOR EXAMINING FINISHED METAL SURFACES AND ITS APPLICATION TO AIRCRAFT-ENGINE CYLINDERS

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A POSITIVE-REPLICA TECHNIQUE FOR EXAMINING FINISHED METAL SURFACES AND ITS APPLICATION TO AIRCRAFT-ENGINE CYLINDERS

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INTRODUCTION

It is often desirable to have a permanent and accurate record of the surface-finish variation of aircraft-engine parts subject to wear. In many cases, a photomicrograph of the desired surface cannot be made without sectioning the specimen. This sectioning is often inadvisable because the specimen may be needed for further tests. Special cameras have been devised for taking photomicrographs of otherwise innaccessible surfaces, but the mechanical difficulties and the expense of such instruments have necessitated the adoption of other methods, such as the use of thin-film replicas.

The use of plastic-film replicas of metal surfaces is not new. In 1924, L. V. Foster (reference 1) used collodion films to obtain replicas of etched surfaces; these replicas were satisfactory for microscopic examination of the etch pattern. Recently, thin-film replicas of metal surfaces have been used extensively in the field of electron microscopy (references 1 to 6). Extremely thin films of collodion and other plastic materials such as Formvar have been stripped from the etched surfaces of metals and have been examined at high magnifications to determine the fine structure of the metallic surface. Lacquer-film negative replicas have been used by the NACA in surface-porosity determinations of chromium-plated aircraft-engine cylinder barrels and have been found to give adequate definition (reference 7). This method, developed by Machlin and Stokel at the Aircraft Engine Research Laboratory, is rapid and satisfactory for the specific purpose of differentiating between the pores and the nominal surface of porous chrome plate. The transparent negative replica is an inverse image of a surface and, if the replica is obliquely lighted or if the original surface was irregular, the replica may bear no resemblance to the original. For a critical study of surface irregularities by means of replicas, the replicas used should therefore be opaque positives of the original surface.

The comprehensive study of aircraft-engine wear undertaken in recent years has focused attention on the physical alteration of wearing surfaces. In most cases the surface change is of such microscopic dimensions that specialized and expensive equipment must be used to examine the interiors of aircraft bearings and engine cylinders. If photomicrographs are taken of the surface for a permanent record, only an extremely small area can be included in the field. Many photomicrographs must be made to obtain a representative concept of the surface. The need for some simpler method of examination that could be applied to any surface without necessitating the use of special equipment was realized during the course of a program of surface-finish study at the Aircraft Engine Research Laboratory in the summer of 1943. A method utilizing positive replicas was developed that overcomes many of the previous difficulties of surface examination in confined bearing and cylinder-barrel areas.

PREPARATION OF NEGATIVE REPLICA

The surface of the specimen is thoroughly washed with petroleum ether and is then swabbed with acetone. A special stripping lacquer that peels easily from a metal surface is then spread in a thin layer over the surface of the specimen with a brush or a clean glass rod. Small specimens may be dipped in the lacquer and set on edge to drain. A stream of air may be directed over the lacquer-coated specimen for 15 minutes to hasten drying, if the air velocity is kept low enough to prevent blushing and wrinkling of the film by the blast. The film is then stripped from the surface to remove any adhering foreign particles not removed by the washing. If the surface is porous or granular, it may be necessary to strip off more than one cleansing film to remove all the material lodged in the surface pores. These cleansing films are discarded.

The final negative replica film is spread on the specimen and a gentle flow of air is directed across the lacquer film for at least 45 minutes before it is carefully peeled from the surface. If the replicas are dried in still air, cleansing films should be left on the specimen for at least 1 hour and the final replica film should be allowed to remain for at least 4 hours before being peeled from the surface. No reduction in shrinkage is gained by allowing the film to remain in place on the surface for a longer time.

PREPARATION OF POSITIVE REPLICA

The preparation of the positive replica consists essentially in plating a thin layer of silver on the replica side of the transparent negative lacquer replica. The dried negative replica film is cut into 1-inch squares that are mounted replica side up over a 5/8-inch-diameter hole punched in a specimen holder made of thin brass plate. The edges of the film are cemented to the specimen holder with some of the lacquer. The negative replica film contracts to a flat surface as the cementing lacquer dries. A glass plate is placed in contact with the back of the specimen holder and both are placed in a high-vacuum metal-evaporation unit where an opaque coating of silver is evaporated onto the replica side of the film (reference 8).

The replica then may be examined microscopically by viewing the opaque silver coating through the lacquer film. The surface thus seen is a positive replica of the original metal surface. If permanent microscope-slide mounts are desired, a 1/2-inch-diameter disk may be cut from the center of the positive replica and mounted silver side down on a microscope slide previously dipped in a fresh warm 10-percent water-solution of gelatin. The slide should be allowed to dry for at least 12 hours. If the negative replica film is dirty, wrinkled, or otherwise unsatisfactory, it may be dissolved from the slide with acetone and a new film of the lacquer applied. The silver replica remains fastened to the gelatin during this process.

FIDELITY OF REPRODUCTION

Surface tests were made to see if the replicas shrink on drying. A series of tests was performed using negative replicas that had dried for different lengths of time in contact with a specimen. Two parallel scratches 2 inches apart were ruled on a polished brass surface and the negative replicas were peeled from this surface and measured at time intervals up to 1 week. The variation of the spread of these two lines from the 2 inches on the original plate was measured on the negative replicas with a scale and a magnifier. The shrinkage was measured to an accuracy of 0.1 percent. Several hundred measurements were made on 75 replicas to obtain the drying-time information previously given. In general, a 1-percent shrinkage should be taken into consideration in all replica studies.

Figure 1(a) is a photomicrograph of a metallographically polished steel surface; figure 1(b) is a photomicrograph of its

positive replica. Figures 2(a) and 2(b) present a similar treatment of a lapped steel surface. The square holes that are visible in the photomicrographs were made with a Rockwell hardness tester. These figures show the degree of fidelity of reproduction possible with the positive replica. The specimen shown in figure 1(a) had a roughness of 1.5 microinches, rms, as determined by the Brush surface analyzer. Figure 1(b) illustrates the resolution possible with the positive replica at the small roughness value of 1.5 microinches, rms.

The higher reflectivity of a silver surface as compared with a steel surface must be considered in interpreting surface character. The fine structural detail is sometimes less evident than it is in the original specimen because of the increased specular illumination of the pits and grooves of the replica. Although the fine detail shown in figure 2(a) is also shown in figure 2(b), figure 2(b) shows much less contrast. In making of photomicrographs of positive replicas, only two-thirds the exposure given to the original steel surface is necessary.

APPLICATION OF TECHNIQUE TO A STUDY OF AIRCRAFT-ENGINE CYLINDER SURFACES

A surface-finish study of cylinder-barrel walls was conducted supplementary to a series of ring-sticking tests on a single cylinder from an Allison V-1710 engine. Positive replicas (figs. 3 to 14) of the cylinder walls were made after each of 22 test runs and were examined microscopically for surface changes during the run-in and wearing of the cylinder barrel. In this application, a negative replica was made of both the major-thrust and minor-thrust faces of the barrel. Selected portions were cut from each of these negative-replica sections and made into finished positive replicas mounted on microscope slides.

A microscopic examination of these positive replicas indicated a gradual erosion and alteration of the cylinder surface from the cross-hatched finish of a newly honed cylinder barrel to the parallel-scratch finish of a well-worn barrel. The top portion of the barrel showed a maximum of wear. This evidence of wear, shown by the disappearance of the honing marks on the barrel area traversed by the rings, decreased down the circumferential barrel area until, at the bottom of the area of ring travel in the barrel, the cross-hatched surface was still quite evident.

Figures 3 to 7 are photomicrographs of positive replicas of various portions of the surface of the cylinder magnified 112 diameters. The coarsely honed surface finish of a new Allison cylinder

barrel is shown in figure 3. Figure 4 shows the comparatively finely honed finish given to the Allison cylinder barrel at AERL in the course of a general engine overhaul. The surface of the coarsely honed new cylinder after 48 hours of test running is shown in figure 5 and the surface of the finely honed cylinder barrel after 35 hours of test running is shown in figure 6. Figure 7 shows the surface of the coarsely honed cylinder after 100 hours of test operation. All these photomicrographs were taken along the middle portion of the major-thrust face of the barrel and represent the general surface appearance of the cylinder barrel.

The first visible change during operation in the surface of the newly honed cylinder is a gradual appearance, early in the test runs, of vertical scratches superimposed on the honing marks. As the wear proceeds, however, three groups of burnished bands begin to appear on the cylinder wall at right angles to the direction of the stroke. The top group has only one sharp band generated by the top compression ring at the top of ring travel in the barrel; the bands formed by the other two compression rings are extremely faint. The second group consists of two closely spaced faint bands that are caused by the two oil-control rings when the piston is at top center. The bottom group consists of three diffuse rings that are generated by the three compression rings at the bottom of ring travel. These bands are probably caused by a number of factors, such as the inertia forces of the piston at the top and bottom of the stroke that give rise to a slapping action of the rings against the wall, as well as the absence of adequate lubrication during the reversal of piston direction.

The rest of the surface of the cylinder barrel other than the band areas contains many fine scratches parallel to the direction of the stroke. These scratches are caused by the abrasive action of particles suspended in the oil and imbedded in the ring or cylinder wall. When the final honing marks disappear from the bottom ring band of the cylinder barrel, the barrel has reached its final surface-finish appearance.

In a coarsely honed new cylinder, the honing marks at the top of the barrel were found to disappear after approximately 100 hours of running time; but, in a finely honed cylinder, these marks disappeared after as little as 30 hours of running time.

An examination of the complete positive replica of the cylinder wall indicated that there were three main areas of interest: the top and bottom ring bands, and the general wall area between these bands. In order to show the difference in the appearance of a recently run-in barrel from that of a well-worn barrel, photomicrographs were made of these three areas in three barrels, one of which

had been run 33 hours, one 120 hours, and the other 225 hours on a test stand. These photomicrographs are shown in figures 8 to 14. The fact that the cylinders examined in this replica study were used for ring-sticking tests must be kept in mind in interpreting the figures. In the cylinders that had been run for 33 and 225 hours, the top ring was stuck in the ring groove causing a different pattern on the cylinder wall at the top of ring travel from that which is found at the same position in the barrel that had been run for 120 hours where all the rings were free.

Figure 8 shows the area within the top ring band in the cylinder in which the top ring did not stick. The looping scratches were presumably generated by the top compression ring as it rotated slightly at the top of the stroke. Figure 9 shows the area at the top of ring travel in the barrel run for 33 hours in which the top ring was stuck. The burnishing effect of the ring impact has removed the scratches in this barrel but has left the deeper cross-hatched grooves of the honing operation. Figure 10 shows a replica of the worn surface of the barrel run for 225 hours taken at approximately the same area shown in figure 9. The ring was stuck in this cylinder. This cylinder presents an excellent example of the surface found at the top of ring travel in a worn cylinder barrel. A characteristic burnished area with the fringe of smeared metal extending downward is clearly shown.

A replica of a typical surface area in the center of the barrel slightly worn after 33 hours is shown in figure 11. This surface has not yet reached the appearance of the barrel shown in figure 5. Figure 12 shows the same general area in the barrel well-worn after 225 hours. An examination of the replicas of this area made from this cylinder during its running indicated that apparently no further surface-finish change occurred once this stage had been reached. (Cf. figs. 6, 7, and 12.)

Figure 13 is a replica of the area containing the ring band at the bottom of ring travel in the barrel slightly worn after 33 hours. The ring bands have not yet begun to appear in this area. Figure 14 shows the top ring band at the bottom of ring travel in the worn barrel after 225 hours. In this area, the burnishing effect is not so noticeable as it is at the top of ring travel, but the fringe of smear metal is quite evident. At the top of ring travel the smear points downward whereas, at the bottom of ring travel the smear points upward. The edges of the smears shown in figures 10 and 14 start, in each case, at the forward edge of the ring as it leaves either the top or the bottom position of ring travel.

The replicas of the major-thrust and minor-thrust faces of the cylinder barrel showed no apparent difference in the rate of wear of the two faces.

SUMMARY OF RESULTS

The positive replicas of metal surfaces made by a method developed at AERL were faithful reproductions of the original surfaces, even at magnifications of 100 diameters.

The positive replicas made of the surface of an Allison V-1710 single cylinder before and after ring-sticking tests showed:

1. A variation in the cylinder surface occurred during the course of the ring sticking tests. The surface finish changed from the rough cross-hatched appearance of the newly honed cylinder barrel to a fine parallel-scratched finish. As the tests proceeded, a series of bands appeared in the barrel surface at the top and bottom of the stroke. The band formed by the top compression ring at the top of the stroke consisted of a band of burnished metal with a fringe of smeared metal extending downward toward the center of the barrel wall. At the bottom of the stroke, the bands were fainter and the burnishing effect was less than at the top of the stroke. The fringe of smeared metal was present, and extended upwards toward the center of the barrel wall.

2. When the top compression ring had stuck in the piston land, the cylinder surface at the top of the stroke ended abruptly with the burnished band and the smeared metal fringe. All the wear scratches were parallel to each other and to the direction of piston motion. When the top compression ring did not stick, this area of the top of ring travel was relatively smooth with numerous looping scratches of different heights superimposed on the general surface. These looping scratches were presumably caused by the abrasive action of particles caught between the piston ring and the cylinder wall at the top of the stroke. The piston ring apparently rotated slightly at the top of the stroke, scraping the abrasive particles across the cylinder wall in a looping motion.

3. There was no apparent difference in the rate of wear of the major-thrust face and the minor-thrust face. The top portion of the cylinder barrel, however, did show a greater amount of wear than the bottom portion.

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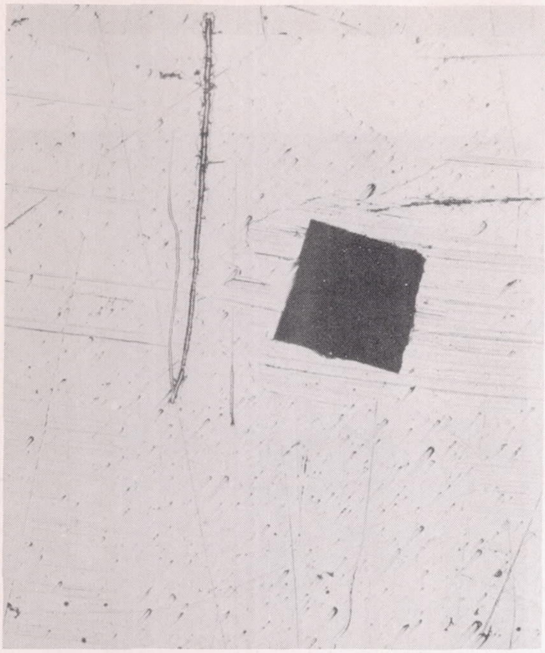
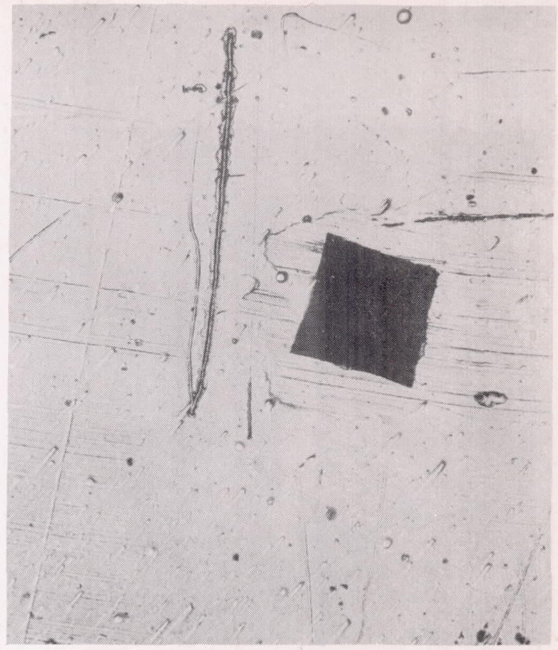


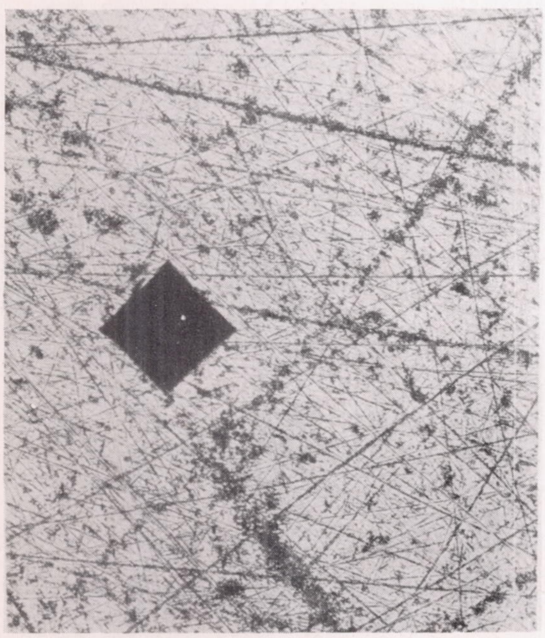
(a) Photomicrograph of surface.

Figure 1. - A metallographically polished steel surface with a roughness of 1.5 microinches, rms. X100.



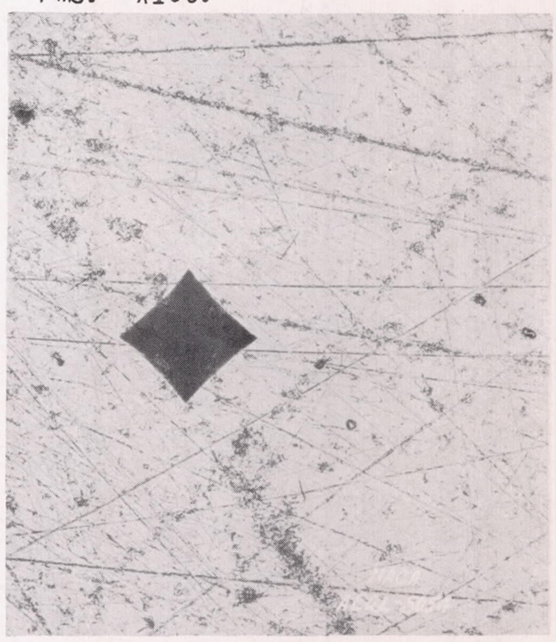
(b) Photomicrograph of positive replica of surface.

Figure 1. - A metallographically polished steel surface with a roughness of 1.5 microinches, rms. X100.



(a) Photomicrograph of surface.

Figure 2. - A lapped steel surface with a roughness of 8.0 micro-inches, rms. X100.



(b) Photomicrograph of positive replica of surface.

Figure 2. - A lapped steel surface with a roughness of 8.0 micro-inches, rms. X100.

Figure 3. - A positive replica of a new coarsely honed Allison V-1710 cylinder barrel. X112.

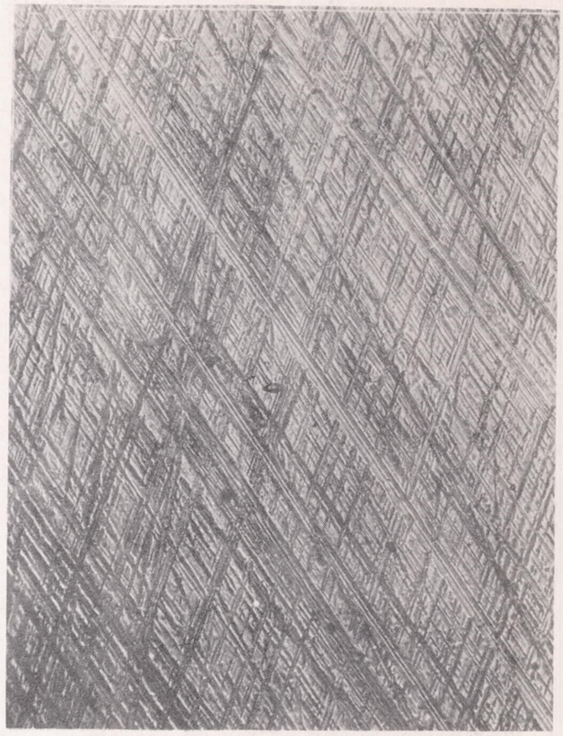


Figure 4. - A positive replica of a finely honed Allison V-1710 cylinder barrel. X112.

Figure 5. - A positive replica of the coarsely honed Allison V-1710 cylinder barrel after 48 hours of test running. X112.

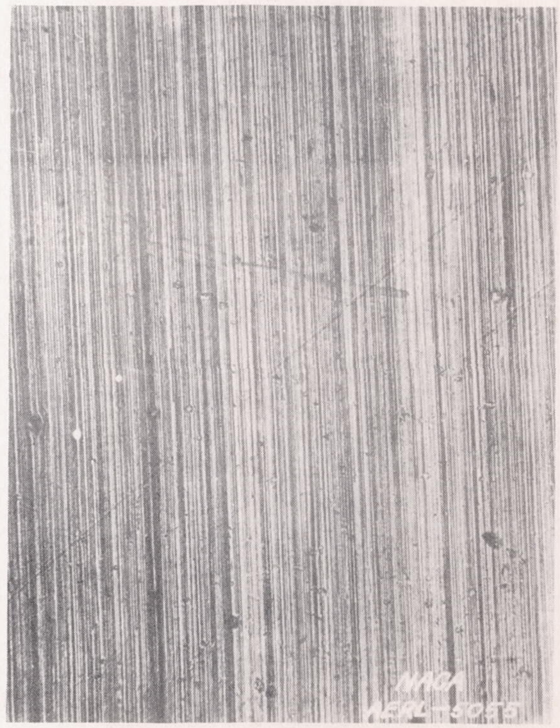


Figure 6. - A positive replica of the finely honed Allison V-1710 cylinder barrel after 35 hours of test running. X112.

Figure 7. - A positive replica of the coarsely honed Allison V-1710 cylinder barrel after 100 hours of test running. X112.

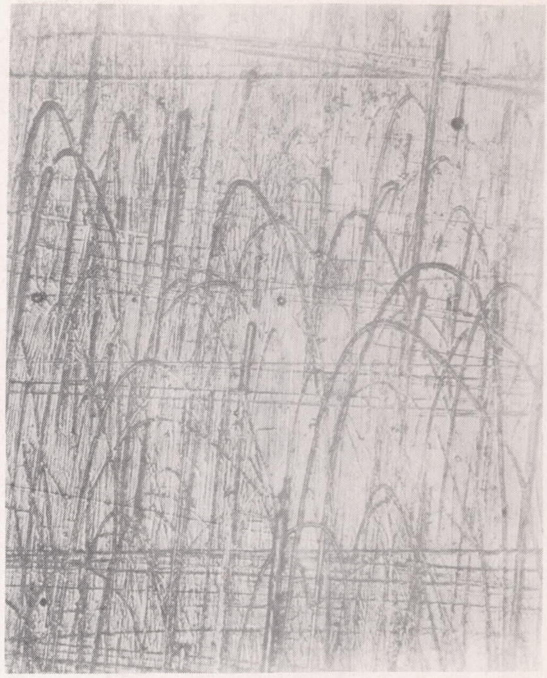


Figure 8. - A positive replica of the area at the top of ring travel in an Allison V-1710 cylinder barrel after 120 hours of test running. The top ring was free. X112.

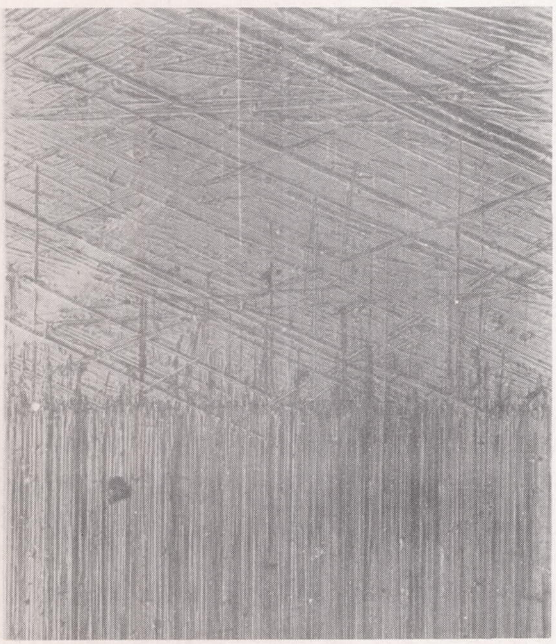


Figure 9. - A positive replica of the area at the top of ring travel in an Allison V-1710 cylinder barrel after 33 hours of test running. The top ring was stuck. X112.

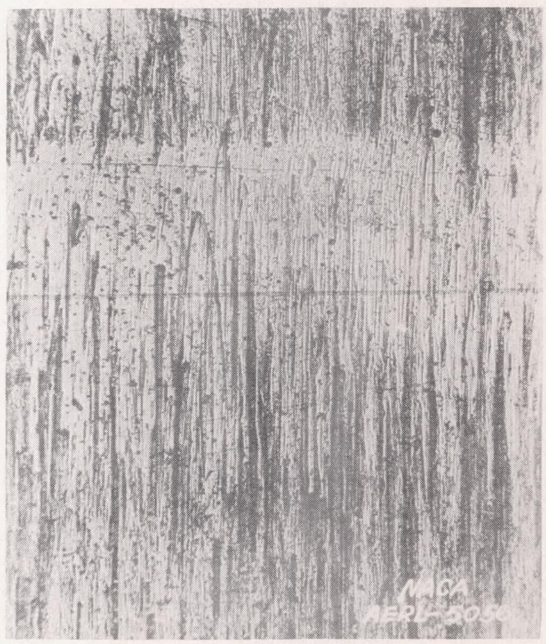


Figure 10. - A positive replica of the area at the top of ring travel in an Allison V-1710 cylinder barrel after 225 hours of test running. The top ring was stuck. X112.

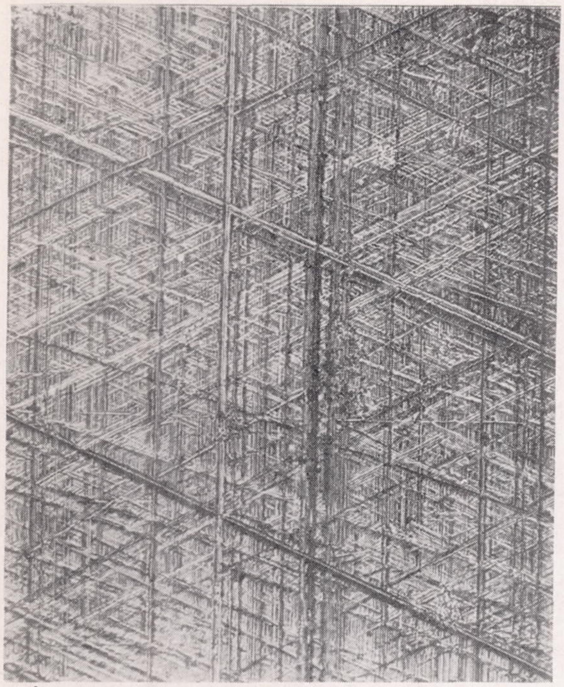


Figure 11. - A positive replica of the general surface area in an Allison V-1710 cylinder barrel after 33 hours of test running. X112.

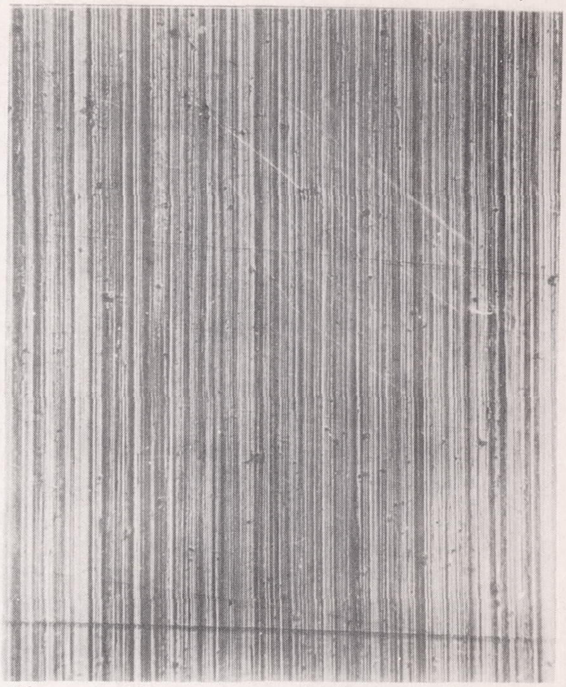


Figure 12. - A positive replica of the general surface area in an Allison V-1710 cylinder barrel after 225 hours of test running. X112.

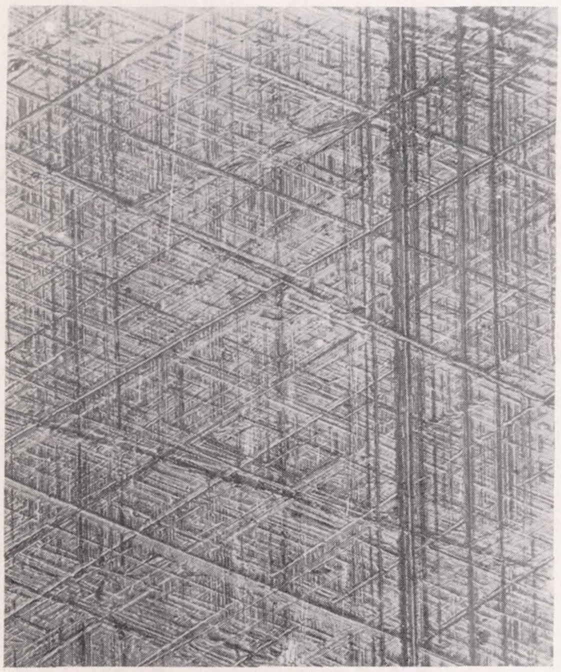


Figure 13. - A positive replica of the area at the bottom of ring travel of the top ring in an Allison V-1710 cylinder after 33 hours of test running. X112.

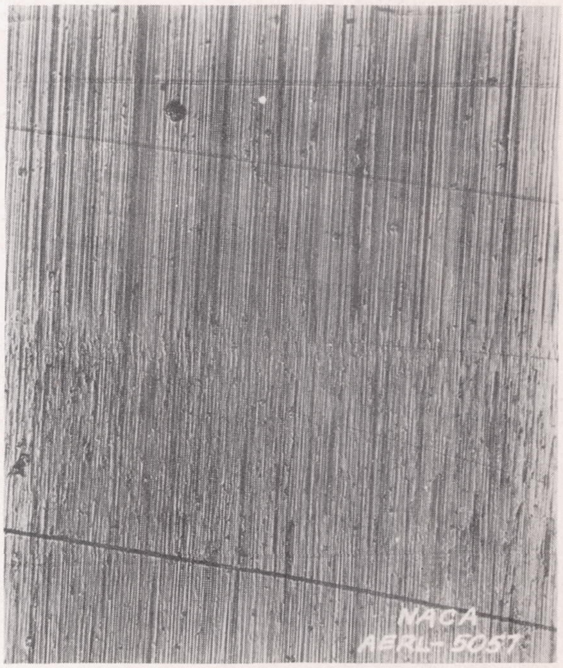


Figure 14. - A positive replica of the area at the bottom of ring travel of the top ring in an Allison V-1710 cylinder after 225 hours of test running. X112.